1. IC7.2 Part 1: WSR-88D Winter Weather Precipitation Estimation

Instructor Notes: Welcome to lesson two in the winter AWOC 7th instructional component. We will be talking about winter weather precipitation estimation in relation to the WSR-88D. This lesson should last about 30 minutes. Part 2 of this lesson is an interactive exercise at the end of the lesson.

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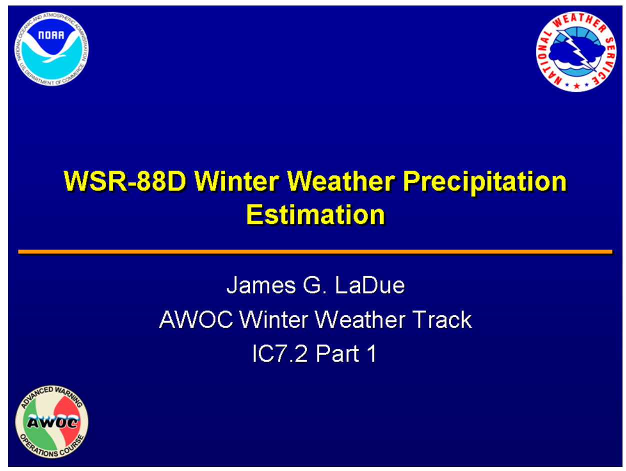

2. Motivation for This Lesson

Instructor Notes: This lesson fits well in the Instructional Component 7 because we will be talking about how well the WSR-88D estimates precipitation. In the short-range forecasting period, observational data of precipitation rate is the single most important data set. Gauge and spotters provide the best point by point reports of winter precipitation rate, but the WSR-88D provides the greatest spatial detail. But there are a lot of errors in relating radar reflectivity returns to actual snowfall rate. The good news is that most of these errors can be accounted for as long as you keep in mind a few strategies and considerations for detecting them. Pretty soon, the ZS algorithm will be viewable on AWIPS when you get OB7. There will be a lot of extra data like snow depth and snow water equivalent. This lesson will describe radar-based precipitation intensity issues with respect to the output of the ZS algorithm.

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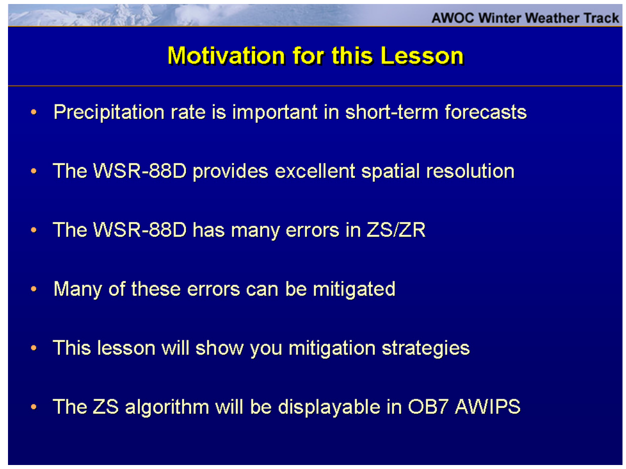

3. WSR-88D Precipitation Intensity Topics

Instructor Notes: Five considerations adversely affect good precipitation estimates, and especially snowfall. Limited range becomes exacerbated in the winter when cold temperature microphysics routinely occur closer to ground. Bright banding becomes more of an issue as the freezing level is low enough to interfere with the hybrid scan selection. Evaporation below the lowest radar beam.

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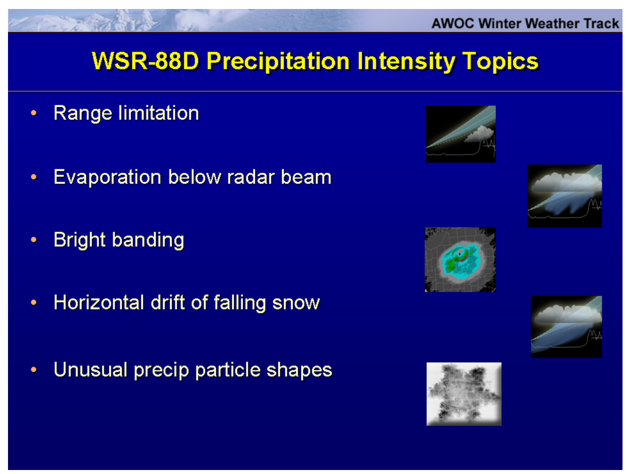

4. Objectives

Instructor Notes: The objectives of this lesson are to identify areas on your radar domain where precipitation estimates are likely to be wrong. We will introduce the error sources that are most likely creating errors and then talk about ways to identify them and compensate for the errors. Some of these error sources are easier to account for than others. For example, bright banding is a source of error that typically results in overestimating precipitation while horizontal drift in falling snow may result in over- or underestimates of your precipitation estimations.

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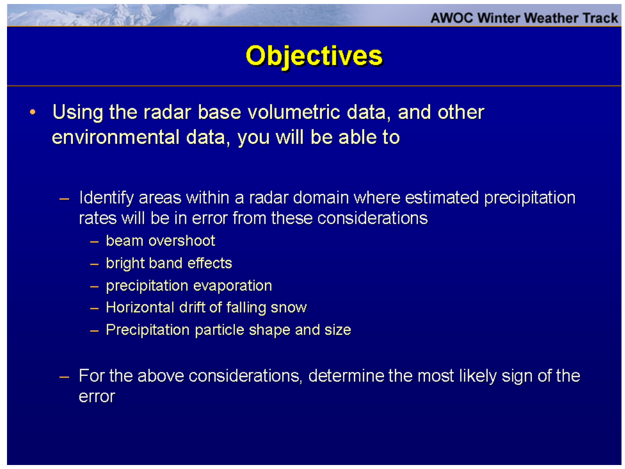

5. Performance Objectives

Instructor Notes: This is one performance objective that you should be able to demonstrate at the end of the lesson. Given radar, surface, sounding and geographical data, you should be able to use the material this lesson presents to determine if the radar is most likely under or overestimating precipitation rate. You should also be able to determine one or more sources of error may exist.

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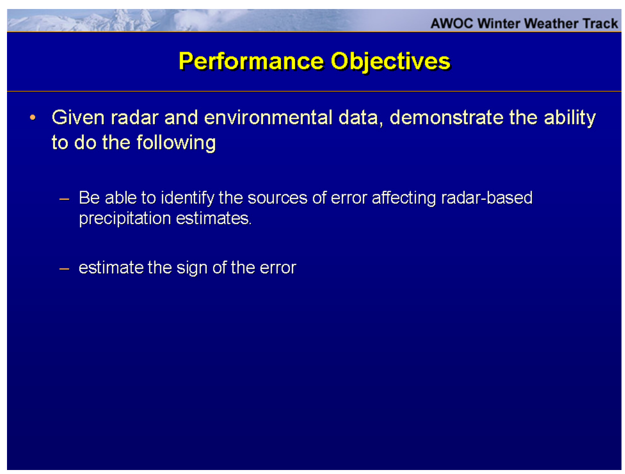

6. Snow Accumulation Algorithm (SAA) Adaptable Parameter Regions

Instructor Notes: The ZS algorithm, first deployed in the RPG in 2004, is now viewable in AWIPS. The Bureau of Land Management worked with the NWS to determine the most appropriate ZS algorithm for geographical regions. A representative office in each geographical region was the site of a one or more season's worth of high quality snow spotter data, where spotters not only sample snow depth but liquid equivalent too. After enough data has been collected, Super and Holroyd (1997) fixed the alpha and beta coefficients to one value that represents the minimum error between radar snowfall estimates and ground truth. Adjacent offices are also assigned these same coefficients based on the assumption that similar climatic conditions as the focus office exist, too.

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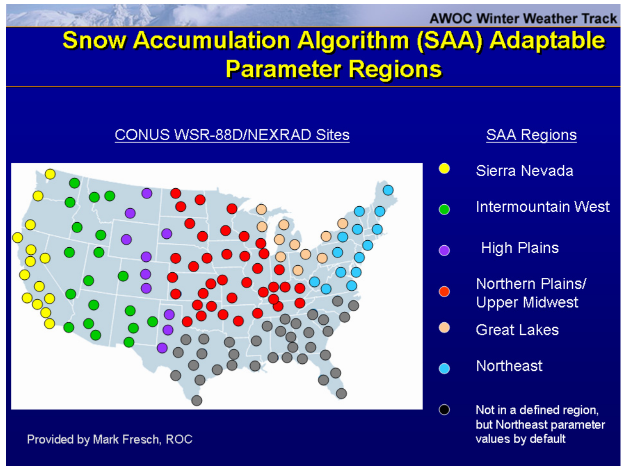

7. Instantaneous Reflectivity into ZS Algorithm Accumulation Rates

Instructor Notes: The default output of the ZS algorithm is liquid water equivalent rate in mm/hr. However, the ZS algorithm output will provide accumulated products of both liquid water equivalent and snow depth, both in English units. By the way, the snow depth will be derived using a fixed snow-to-liquid ratio. The ZS algorithm results show an exponential increase in snowfall rates with reflectivity for any region. The default coefficients are fixed over regions, however the weather is not. Variations in many factors can cause deviations from your default ZS algorithm settings.

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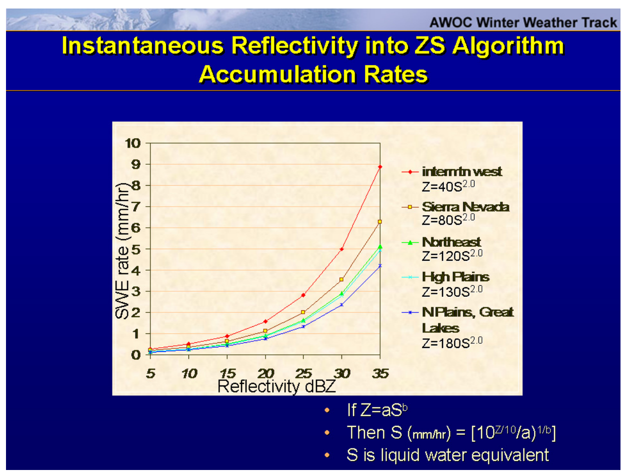

8. WSR-88D Precipitation Intensity Reality

Instructor Notes: Prior to and during the winter Olympics in Salt Lake City, Steve Vasiloff compared radar-based snow depth and SWE accumulations on an hourly basis with that of good quality snow gauges. The scatter is pretty significant. Just to remind you, the KMTX radar is using the ZS algorithm here and that the lowest 'unblocked' elevation angle is 1.5 degrees. The ZS algorithm used is Z=75S1.2.

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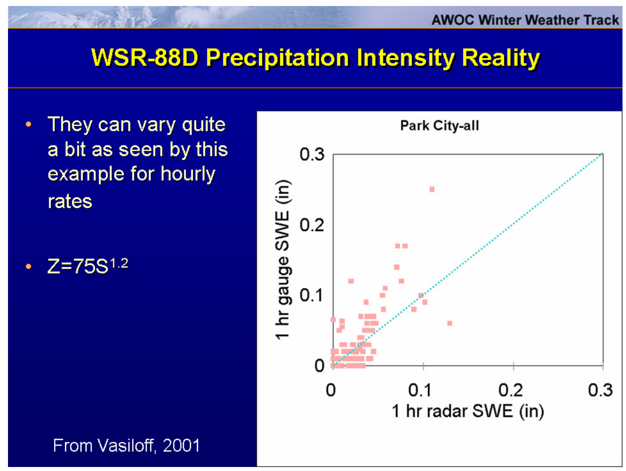

9. WSR-88D Precipitation Intensity Topics

Instructor Notes: Now that we've seen the problems, let's go ahead and discuss some of the strategies to mitigate them. We'll start off with looking at range limitations from radar.

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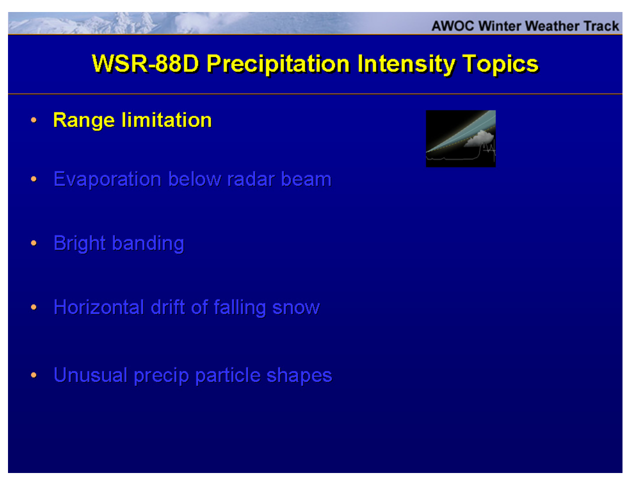

10. Range Limitations

Instructor Notes: Reflectivity begins to degrade once the top end of the radar beam climbs above the precipitation production layer. You're guaranteed to lose the signal once the bottom end of the beam departs the precipitation region. The precipitation generation region is difficult to quantify. One definite zone is the maximum growth layer for dendrites (e.g., the -12 to -18 degrees C layer). However, the presence of high cloud liquid water content in zones warmer than the dendritic growth layer but still below freezing can contribute significant amounts of riming and needles. In warmer saturated regimes, the collision-coalescence becomes active, too. Even the dendritic production layer can be fairly low in very cold weather, even near ground level. All of these precipitation production zones can be shallow and, therefore, cause reflectivity degradation at close ranges to the radar. As a side bar, orographic precipitation can occur very close to mountain sides. The WSR-88D has an exceedingly difficult time separating ground returns from real precipitation when both occur within a range gate. Clutter filtering can reduce or eliminate precipitation in range bins also containing clutter.

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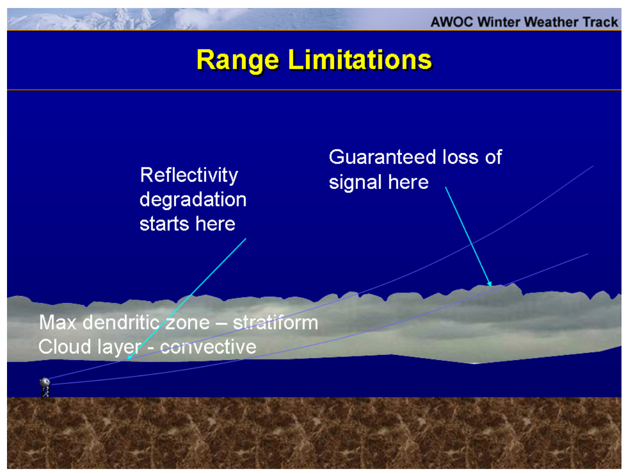

11. Radar Range

Instructor Notes: Here is the radar coverage for CONUS given that the dendrite production zone is relatively high, say > 22 kft. ARL. So for example, if there was a warm advection precipitation event where the dendrite production was the only layer producing precipitation, then expect good sampling by radar. Range limitations in this case are not a big problem. Now, the precipitating layer is lowering. Synoptic situations where this is common often occur in TROWALS, or along frontogenesis zones. Range degradation begins at a lower level and gaps in adequate coverage begins. Orographic clouds often hug the sides of mountains which can mean range is extremely limited. Also, in arctic outbreaks, shallow convection can result in significant snowfall rates, even with the precipitating layer at just 5 kft AGL. I have seen cases of power plant plumes and midwestern reservoirs producing significant snowfall whose cloud tops were only 1000'. Radar is extremely limited in its usefulness. Here is the coverage of typical lake effect snow, and precipitating orographic clouds where the precipitating layer is 8.5 kft AGL.

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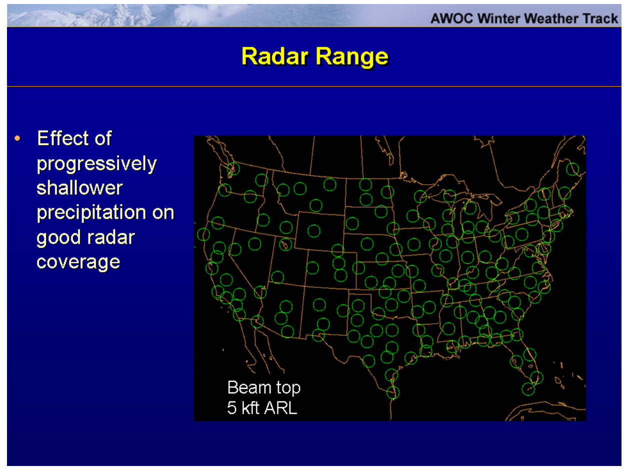

12. How to Estimate Where Beam Overshooting is Possible

Instructor Notes: Here's the rule of thumb: watch out for favored regions where saturation and vertical motion are likely resulting in precipitation production. Your radar should at least sample the dendrite production zone adequately. But even if it does, watch out for feeder clouds that can enhance precipitation through riming, aggregation or coalescence. Even clouds not able to make it to the dendrite production layer can produce significant precipitation. Short distances can result in big changes in precipitation production layers. In convection, precipitation is being produced anywhere updraft is intersecting precipitation in warm layers and in subfreezing air. It is more likely you want to sample the warm cloud layer when the updraft is weak. Of all things to remember, do remember that the cursor readout you see is the beam center point. Reflectivity degradation begins when the beam top exits the precipitation layer.

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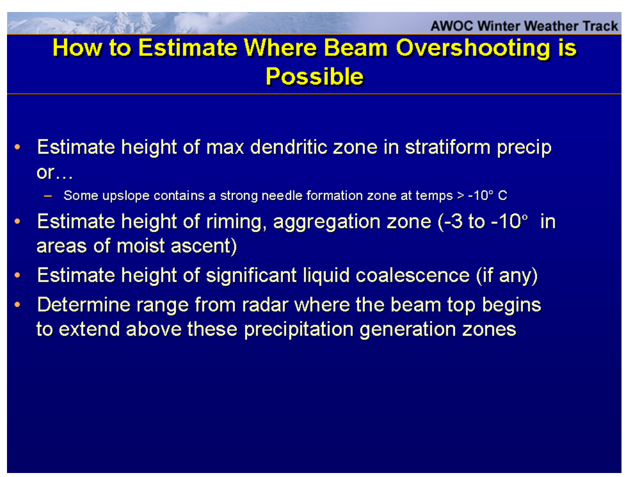

13. How to Figure Good Radar Range?

Instructor Notes: This tool is available on our web site if you would like to use it. Enter in the range of your cursor and your elevation angle. Then calculate beam properties and you'll know the top of your beam. If the beam top is greater than where you believe precipitation is developing, then your radar will underestimate precipitation rate.

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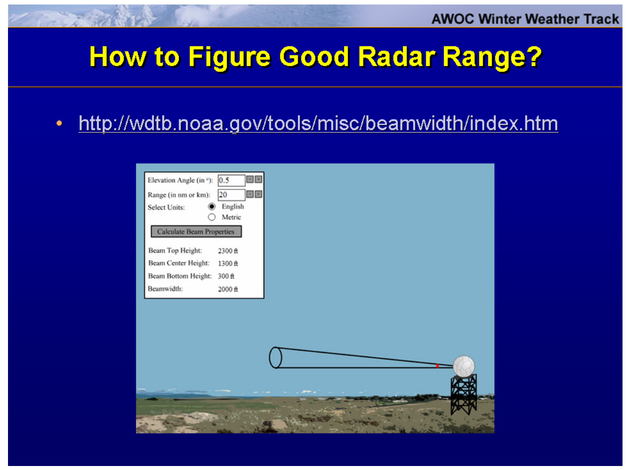

14. Case 1: Estimating Range Limit in the Mountains

Instructor Notes: In this first example, we will look at the major considerations of whether or not you're sampling precipitation generation by looking at a specific site. Alta Collins is a small gauge site at Alta ski area (9662' MSL). The 1.5 degree beam reflectivities is followed by the 0.5 degree beam. Note that there's some beam blockage toward the radar but over the site there are reflectivity data. We will use the reflectivity for each elevation angle and convert it to liquid equivalent rate. There will be one for beam blockage and we'll talk more about that in the next slide.

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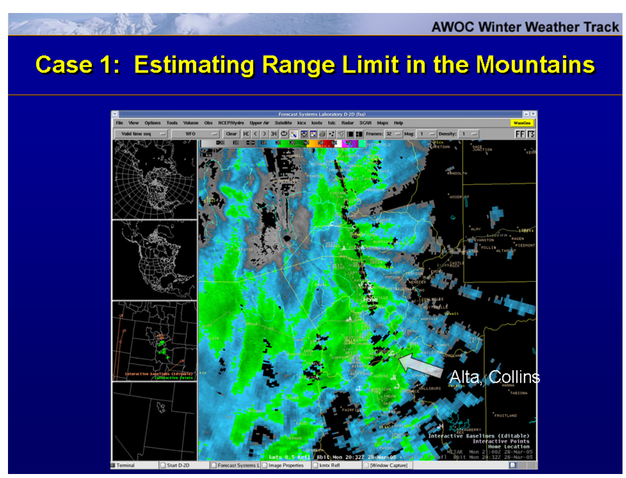

15. Case 1: Location of the 1.5 Degree Beam Relative to the Dendrite Production Layer at Alta

Instructor Notes: Alta is located at the cross-hairs on the RHI scan. It's a high mountain location at the end of the valley that slopes up to the east. Overlaying the Eta12 18 UTC analysis sounding, the dendrite production layer lies just above the mountain ridge. Note the height of the 1.5 degree beam over Alta. Take a look at the beam height relative to the dendrite production layer (the -12 to -18 degree C layer). How do you think the radar would do in sampling the precipitation being caught at the Alta Collins gauge? Here is a scenario: If there were no gauge there, and the DOT requested an estimate of snowfall rates up the canyon leading to that gauge, what would you tell them?

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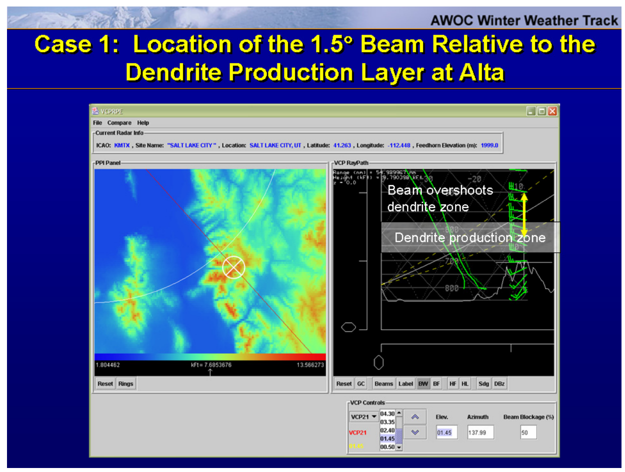

16. Alta Gauge Catch vs. Radar 1.5 Degree ZS Accumulation of SWE

Instructor Notes: It is not surprising the radar is not sampling the production of snow in the -12 to -18 degree C layer when using the 1.5 degree elevation scan. Let me remind you ahead of time that I am using ZS coefficients that will be operationally in use for the same radar. I could simply adjust the coefficients to match the radar estimations to what we observe for any one time interval. However, look at the trends to show how different sampling errors come into play at different times. Any singular change to a ZS algorithm coefficient will simply change the whole time trend. With the 1.5 degree scan precipitation estimations, I could change the coefficient and lift the whole time trend up and attempt to minimize the error with the Alta gauge. It's important to note that I would not improve on changing the radar precipitation estimation errors over time. In other words, change the shape of the time trend to match the observations. Anyway, I haven't even tried using the 0.5 degree scan to see how it improve the radar estimates.

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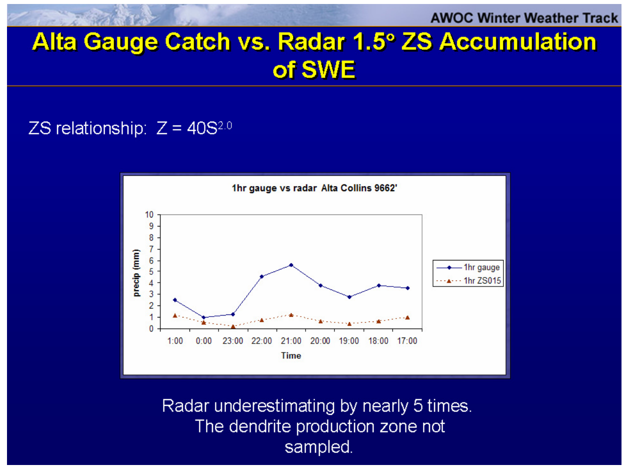
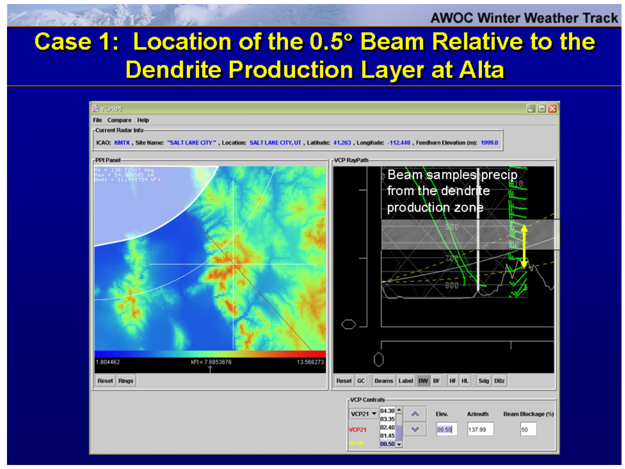


17. Case 1: Location of the 0.5 Degree Beam Relative to the Dendrite Production Layer at Alta

Instructor Notes: How well do you believe the 0.5 degree elevation scan will improve the radar ZS estimates given the same ZS relationship? Do you think the radar is adequately sampling the snow that is falling into the Alta Collins gauge? Note here the relationship between the dendrite production layer (grey rectangle) vs. the vertical extent of the 0.5 degree beam over the Alta site (yellow arrow line segment). The vertical white line represents the approximate distance from the radar where the top of the 0.5 degree beam reaches the -12 degree C layer. Let's say that snowflakes grow rapidly within the dendrite production layer with a bottom at -12 degree C. Then we can say that reflectivity will definitely degrade as soon as the top of the beam enters into this layer. For this example, that's 37 nm away from the KMTX radar. Let's draw a ring around the radar marking 37 nm first on the plan view map on the left and then on a real image in the next page. I want to make you aware that as long as the air is saturated, and there is upward motion, needles can easily form at temperatures warmer than -12 degree C. So anywhere it's below freezing and these conditions are met, there will probably be snow fall production and an increase in reflectivity as you approach the ground. But at least we should catch most of the snow production in the dendrite production layer.

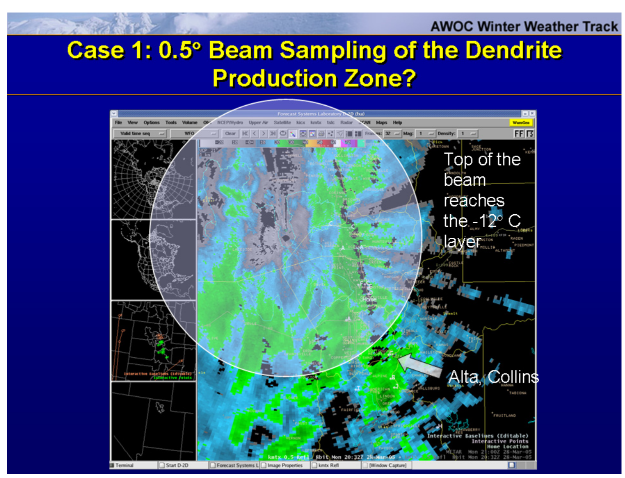
Student Notes:



18. Case 1: 0.5 Degree Beam Sampling of the Dendrite Production Zone?

Instructor Notes: In the white shaded area, the radar beam top is below -12 degree C. Whatever precipitation falls out of the dendrite production zone should be theoretically well sampled by the lowest elevation slice. As you can see, however, we've got beam blockage issues and inhomogeneities in the precipitation field that result in the appearance of reflectivity degradation with range east of the radar. Alta is outside the region where the 0.5 degree elevation slice remains entirely below the -12 degree C layer. Thus we can be almost sure of some reflectivity degradation and, therefore, the radar is likely underestimating the snowfall rates at the ground. As a caution, we have not considered precipitation evaporation between the radar beam and ground. While I stand by my claim above, I must consider if evaporation may prove me wrong. In this case, precipitation has been occurring for awhile and the atmosphere between the radar beam and Alta Collins is likely near saturation. I'll talk more about evaporation later.

Student Notes:



19. Alta Gauge Catch vs. Radar 1.5 Degree ZS Accumulation of SWE

Instructor Notes: It is not surprising the radar is not sampling the production of snow in the -12 to -18 degree C layer when using the 1.5 degree elevation scan. What can the 0.5 degree scan do to improve the radar estimates? Well, there's an improvement. The radar is capturing more of the snow falling into the Alta Collins gauge but there's still a ways to go. The 0.5 degree scan is partially blocked by intervening terrain. The ZS algorithm will adjust for partial beam blockage. There's about 40% blockage here and so let's see if a +4 dB adjustment will close the gap.

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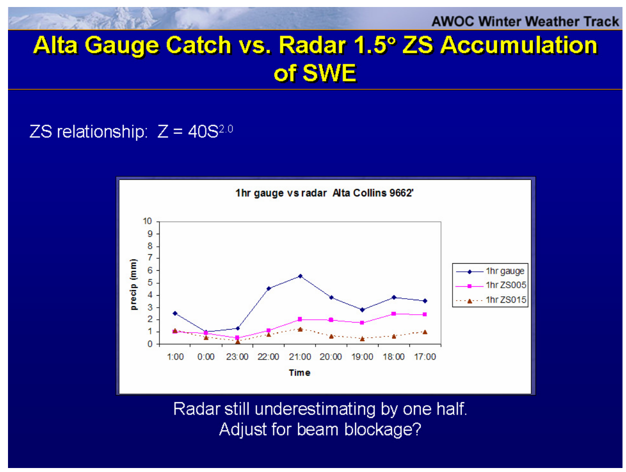
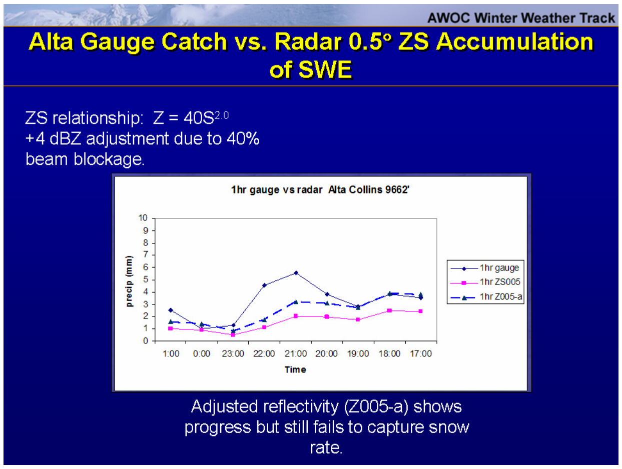


20. Alta Gauge Catch vs. Radar 0.5 Degree ZS Accumulation of SWE

Instructor Notes: Even adding an adjustment to reflectivity from the 30-40% beam blockage, in a similar way to the ZS algorithm, the radar fails to capture the amounts at the Alta Collins gauge from 20-23 UTC. We could lower alpha in Z=alpha*S^{Beta} to 20 but that will increase the radar SWE estimates everywhere and overestimation would result on either side of 20-23 UTC. What is really happening is that most likely there is large amounts of aggregation and riming occurring close to the mountain sides as the upslope flow became more saturated below the dendrite production layer. The radar cannot easily discriminate between these situations because of the beam blockage. A static +4 dBZ adjustment is insufficient when the actual precipitation rate in the blocked area changes with time.

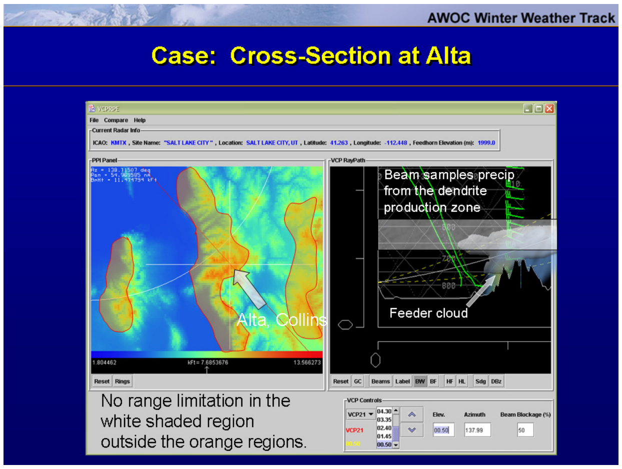
Student Notes:



21. Case: Cross-Section at Alta

Instructor Notes: While the beam is probably sampling the dendrite production zone adequately (even this is not 100% sampled), the enhanced upslope is likely causing strong lifting in the layer just below the maximum dendrite production zone. The result of this situation is stronger lift is quite possibly generating even more snow through needle formation, snow flake aggregation, and riming. For simplicity, we say that the dendrites falling into this layer from above is being fed by this lower-level updraft and so we call this cloud a feeder cloud. The sounding here suggests that this is quite likely. Unfortunately, the radar near Alta has no chance in adequately resolving this feeder cloud layer because of its shallow nature, this layer is rubbing against the terrain, and beam blockage is a constant problem. Anywhere there is cloud in temperatures warmer than -12 degree C, with moist ascent, expect to see continuous precipitation enhancement through ice multiplication, aggregation, riming, and liquid drop coalescence. I expect this problem to be most pronounced on the upslope sides of the mountains here. Assuming no beam blockage, then adequate radar sampling of feeder cloud requires that the top of the beam remain below the LCL. In this example, the LCL is roughly 7500' MSL. The radar altitude is already > 5 kft MSL and so the top of the beam would hit the LCL just 20 miles away. Except for the terrain around Promontory point (upon which the radar is located), no adequate sampling of the LCL region exists and it is likely the radar will underestimate observed precipitation in any upslope region where cloud exists. I will paint these likely regions in orange.

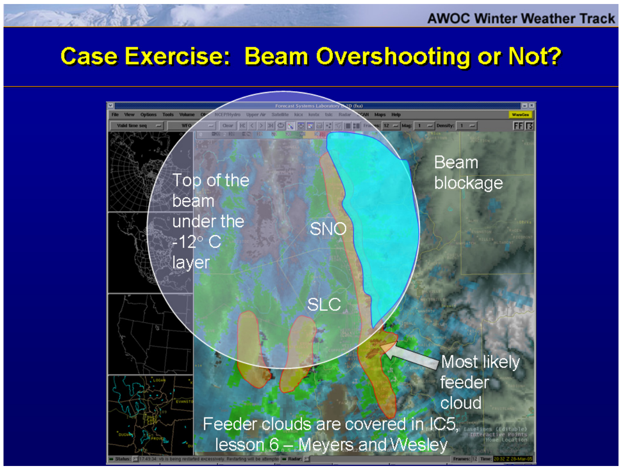
Student Notes:



22. Case Exercise: Beam Overshooting or Not?

Instructor Notes: Going back to the map, here is the 0.5 degree reflectivity image overlaid on the topography. I again overlay the region where the entire beam is below -12 degree C in the white shaded circle. However, beam blockage is limiting reflectivity in large regions east of the Wasatch as represented by the regions in blue. Anywhere with a strong upslope component has the highest probability of the seeder/feeder process and I overlay these in orange. The best range sampling is most likely in areas shaded in white but outside the orange feeder cloud areas and away from beam blockage. I remind you that feeder seeder processes are nicely covered in a lesson on topographic precipitation forcing in IC 5, lesson 6 authored by Mike Meyers of GJT and Doug Wesley of COMET.

Student Notes:



23. Expected ZS Algorithm Range Correction Factor Technique

Instructor Notes: Note that in flat regions, there is a range correction required on a climatological basis. The Bureau of Land Management (Holroyd, 1999) found this adjustment factor to the radar estimated SWE for Minneapolis based on a winter's worth of snow events. Not much adjustment is needed close to the radar but increasing adjustment is required at larger ranges. In actuality, beyond 180 km or so, the lowest beam is overshooting so badly that no adjustment will give you an adequate estimate. This range correction will likely be applied to the ZS algorithm output once it is viewable on your AWIPS. This graph was based on a climatology of one winter. Range corrections would vary widely in very short time intervals, even minute by minute for certain events. And we've already seen how it will change when there's topography.

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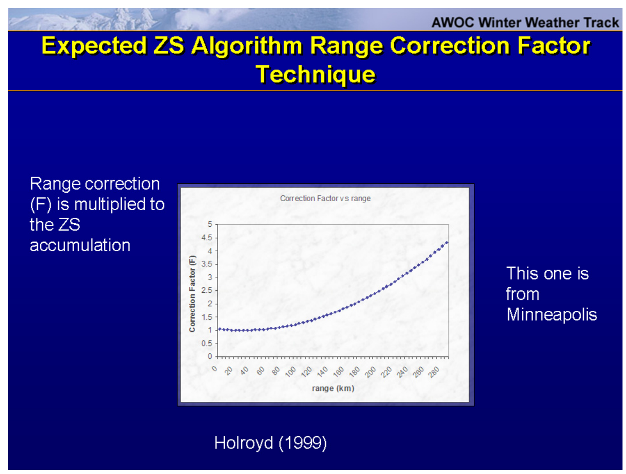


24. Quiz item #1

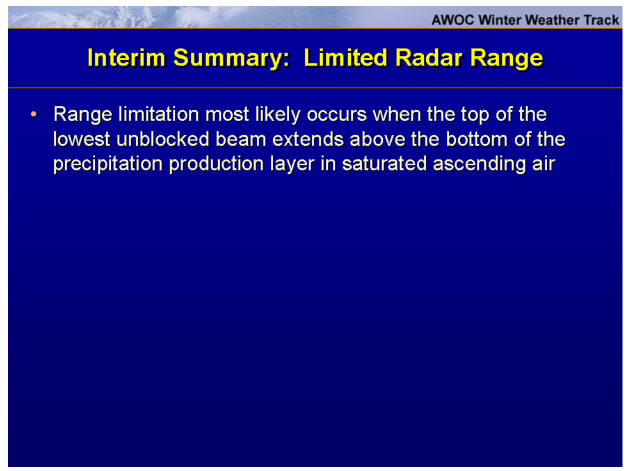
Instructor Notes: Take a moment to complete this interactive quiz.

Student Notes:

25. Interim Summary: Limited Radar Range

Instructor Notes: Range limitation most likely occurs when the top of the lowest unblocked beam extends above the bottom of the precipitation production layer in saturated ascending air. Is your lowest beam fully sampling feeder clouds? In the absence of feeder clouds, where is your beam relative to the dendrite production layer? Range is severely limited in topographic ascent, lake effect, and maritime warm clouds.

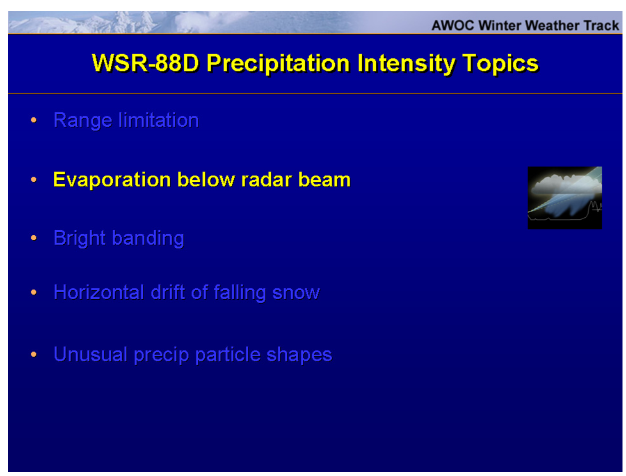
Student Notes:



26. WSR-88D Precipitation Intensity Topics

Instructor Notes: Let’s talk about sub-beam evaporation of precipitation and where it affects radar precipitation estimates.

Student Notes:



27. Low-Level Evaporation

Instructor Notes: The overestimation problem increases with increasing range from the source radar. The KFDR radar in the upper-right shows precipitation over an area where it is clearly virga, as viewed by the KTLX radar. If the environment saturates below the radar beam, this problem would diminish. The problem is if you don't have a nearby radar, how can you tell where the radar is overestimating precipitation rates. We'll look at reflectivity as a proxy for instantaneous precipitation rate and then look at some cases of hourly rates.

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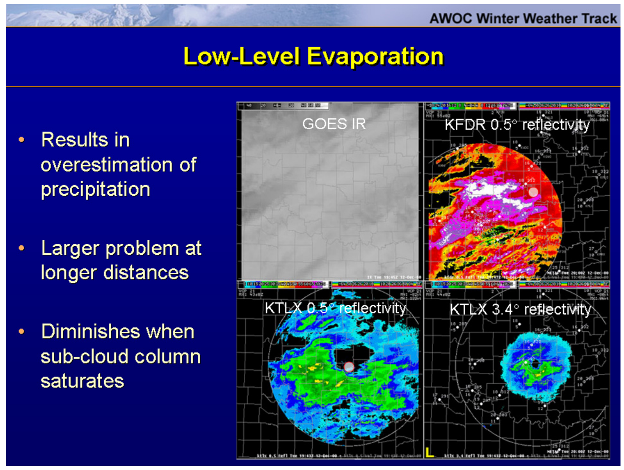
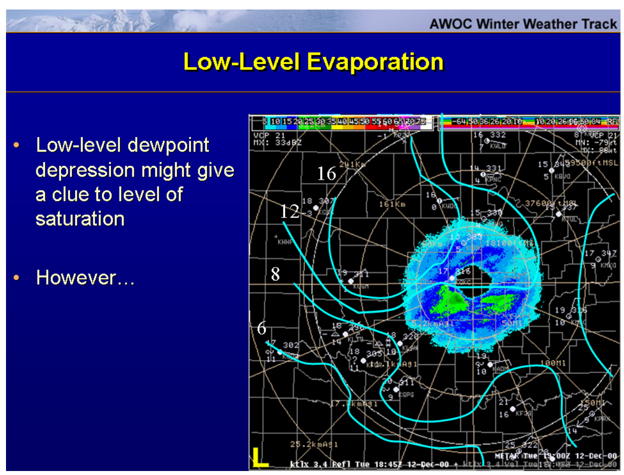


28. Low-Level Evaporation

Instructor Notes: You can clue in on any subsaturated air by observing dewpoint depressions. Remember that these depressions are based on dewpoint, and not frost point. Thus if it's significantly below freezing, you probably will not see dewpoint depressions less than 5 degrees C.

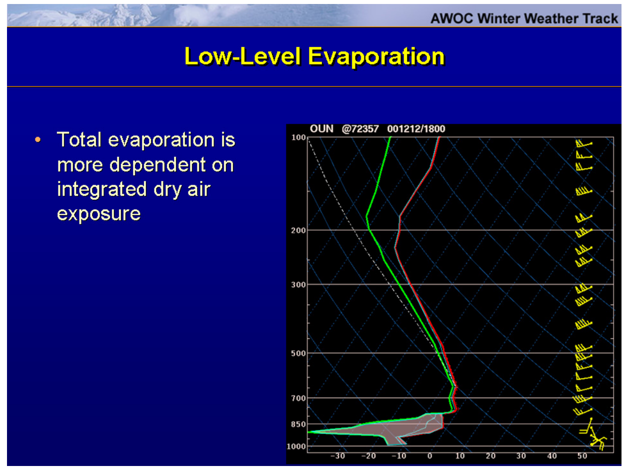
Student Notes:



29. Low-Level Evaporation

Instructor Notes: Surface dewpoint depression in the last page was not entirely representative of the amount of total evaporation that a hydrometeor would experience on its way to the surface. We still know that precipitation rate will be overestimated by distant radars.

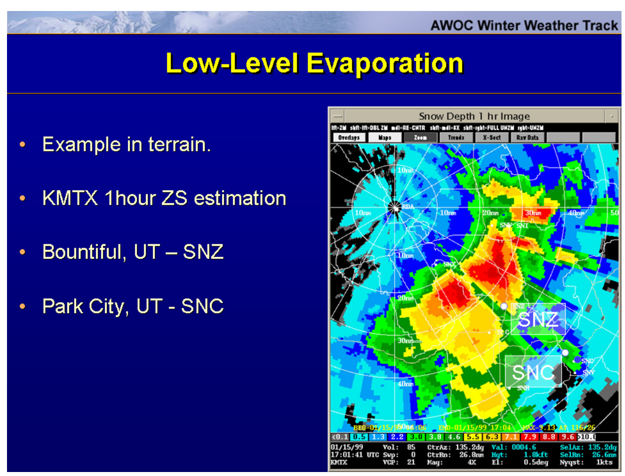
Student Notes:



30. Low-Level Evaporation

Instructor Notes: In significant terrain, some areas routinely experience evaporating precipitation below the lowest scan from your nearest radar. I'll present to you a study comparing gauge catches vs. radar-derived precipitation estimates for several stations in the Salt Lake City area. Vasiloff (2001) studied precipitation rates in this area in preparation for the 2002 Winter Olympics. Here is an example of two stations, Bountiful and Park City, and how their elevations impact catchment. Bountiful (SNZ) is at 5000' MSL and west of the Wasatch mountains while Park City (SNC) is east of the Wasatch crest and at 7000' MSL. This one-hour accumulated snow depth map was created using a ZS relationship. Note that radar estimations over Bountiful were much higher than for Park City.

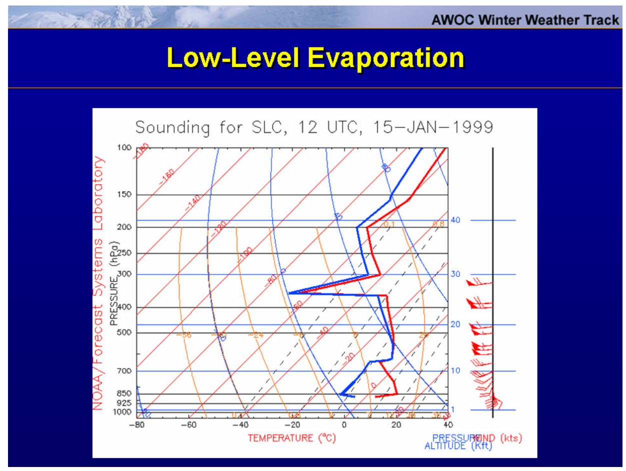
Student Notes:



31. Low-Level Evaporation

Instructor Notes: The sounding from Salt Lake City shows a dry layer extending up to 650 mb. Elevation is an important determinant regarding how much evaporation you will receive.

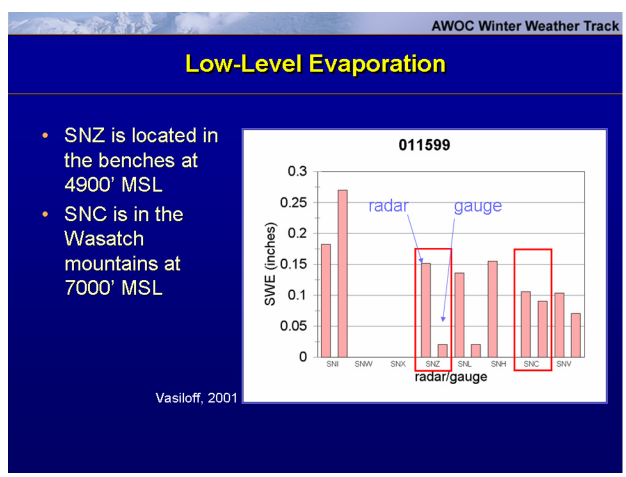
Student Notes:



32. Low-Level Evaporation

Instructor Notes: In the red square highlighting Bountiful's precipitation, note that the gauge recorded much less than the radar estimate. It is also not surprising here that Bountiful received much less precipitation than Park City given the evaporation problems. Meanwhile at Park City, the radar and gauge agree much more. Remember that this is one specific ZS relationship that was used.

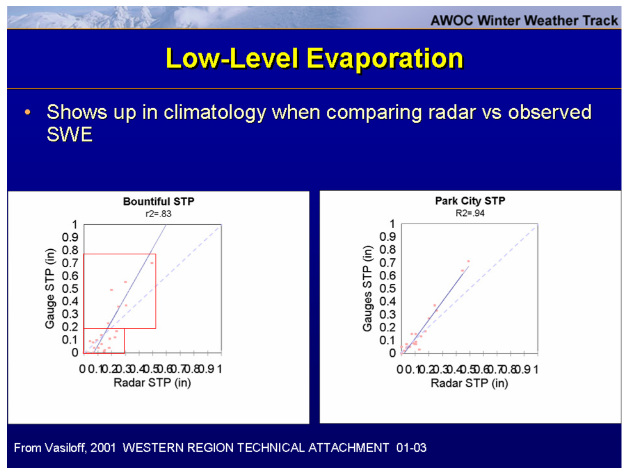
Student Notes:



33. Low-Level Evaporation

Instructor Notes: Here, I show you radar Storm Total Precipitation (STP) from the ZS algorithm vs. the gauge accumulations, both in liquid water equivalent. Over a period of storms, the climatology of evaporation starts to reveal itself. The radar consistently overestimates the ground truth at Bountiful for light snow storms. Note for Park City that the gauge and radar agree much more readily for similarly light events. But for heavier snow storms, the radar actually underestimates precipitation ground truth, especially for Bountiful. Can you name a reason why that might be the case? Vasiloff created an adjustment to the ZS algorithm using the regression curve represented by the solid blue line. However, one has to wait until the snow event is done before the adjustment is made.

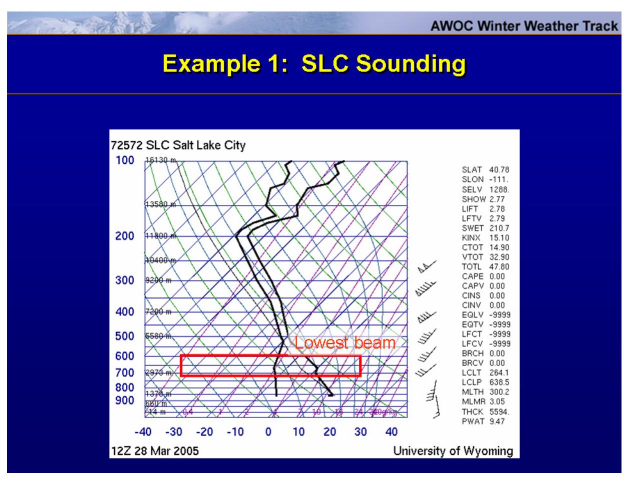
Student Notes:



34. Example 1: SLC Sounding

Instructor Notes: Let's take a look at a case from Salt Lake City. The sounding was taken 6 hours before and shows a typical pre-cold frontal environment with a substantial dry layer up to 550 mb.

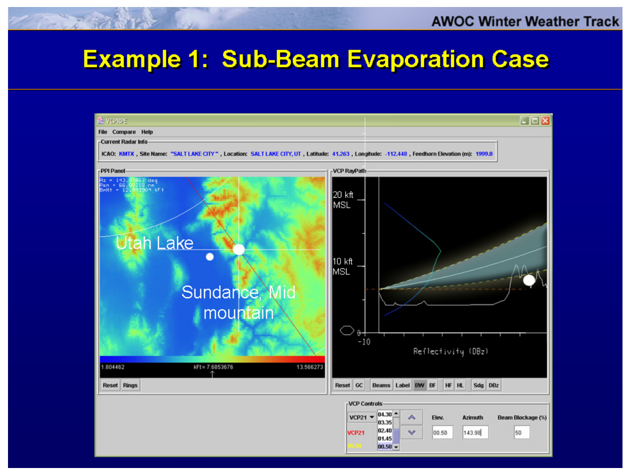
Student Notes:



35. Example 1: Sub-Beam Evaporation Case

Instructor Notes: The Sundance Midmountain gauge is located just below the 0.5 degree beam from KMTX. There is a small amount of beam blockage from higher terrain to the northwest. As precipitation is beginning, we'll assume a vertical reflectivity profile such as the one shown on the cross-section to the right. Note that the reflectivity peaks at 30 dBZ just above mountain top and then trails off to 10 dBZ at the valley floor as sublimation takes its toll. If we assume the true vertical reflectivity profile is the same everywhere, then elevation has a controlling influence on the accuracy of the radar precipitation estimate. The closer you are to the maximum reflectivity, the more precipitation you will see. Let's see how elevation and location affect the accuracy of the storm total precipitation from the KMTX radar in the next page.

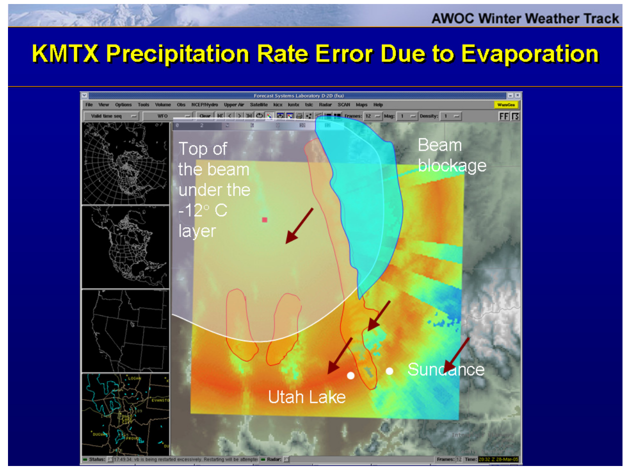
Student Notes:



36. KMTX Precipitation Rate Error Due to Evaporation

Instructor Notes: We'll shortly see how low-level evaporation creates an elevation dependency on the accuracy of the precipitation algorithm. First, I left the zones that we talked about in part one showing where you need to be to adequately sample precipitation emanating from the dendrite production zone. Because it's so early in this event, there are probably not many feeder clouds so we'll take those out. Instead, let's overlay a precipitation rate difference product based on the precipitation algorithm. This adjustment is the difference between the official STP algorithm using the DHR and the true precipitation observed at the ground using the true reflectivity as it intersects the ground. Everywhere you see warm colors, the radar is overestimating precipitation. The further from the radar you go, the warmer the colors or the bigger the difference. But in the higher terrain, you have smaller differences as the terrain approaches the radar beam, and higher reflectivities. This simulates one reason why high terrain observes more precipitation. The green colors represent near zero error. Consider the following questions that you'll be asked in the next page: Is the radar over, under or properly estimating snowfall rate at Sundance? Assume the Z=70S1.4. The blue colors represent the radar underestimating the precipitation. Given the relatively low terrain well southeast of Sundance, how can the radar underestimate precipitation given low-level evaporation issues?

Student Notes:



37. Quiz Item #2

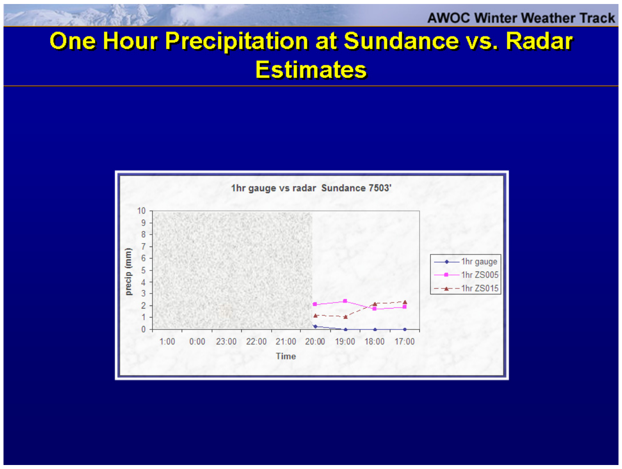
Instructor Notes: Take a moment to complete interactive quiz #2.

Student Notes:

38. One Hour Precipitation at Sundance vs. Radar Estimates

Instructor Notes: The answer is here. Over the period from 17-19 UTC, reflectivities remained high in the lowest two scan elevations but nothing appeared in the Sundance gauge. Evaporation is taking a toll. Finally at 20 UTC, some snowfall reaches the gauge.

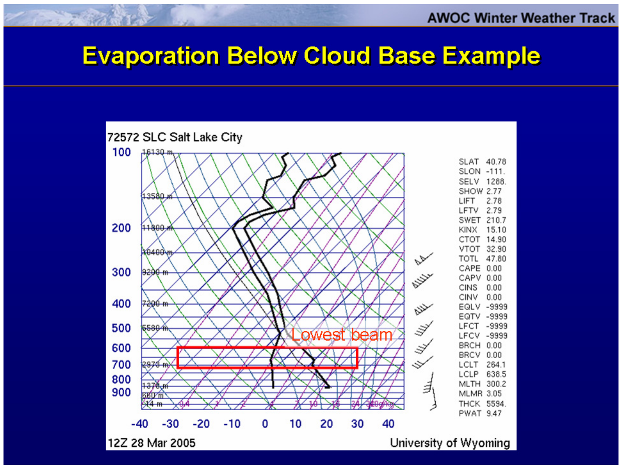
Student Notes:



39. Evaporation Below Cloud Base Example

Instructor Notes: 12 hours later, the cold front passes SLC, and the column is nearly saturated except for the lowest 50 mb. Sundance lies just below the lowest beam from KMTX.

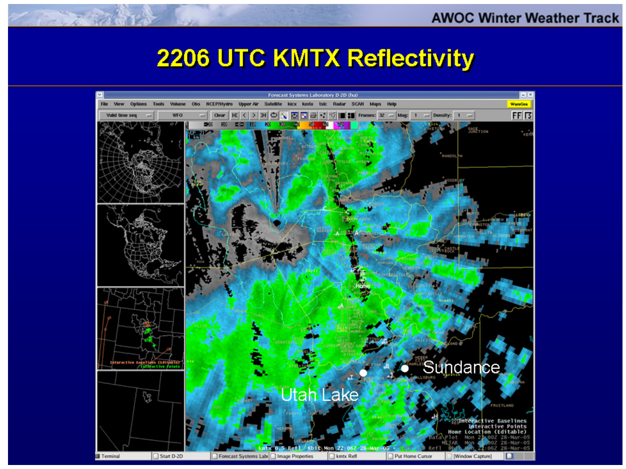
Student Notes:



40. 2206 UTC KMTX Reflectivity

Instructor Notes: Here is a 2206 UTC reflectivity image from KMTX. We'll estimate whether or not the radar will overestimate, underestimate, or be right on with its precipitation measurement. Note that when we do go from 1.5 degree to 0.5 degree, the reflectivity increases slightly over Sundance. Is the radar over, under or properly estimating snowfall rate at Sundance? Assume the Z=70S1.4.

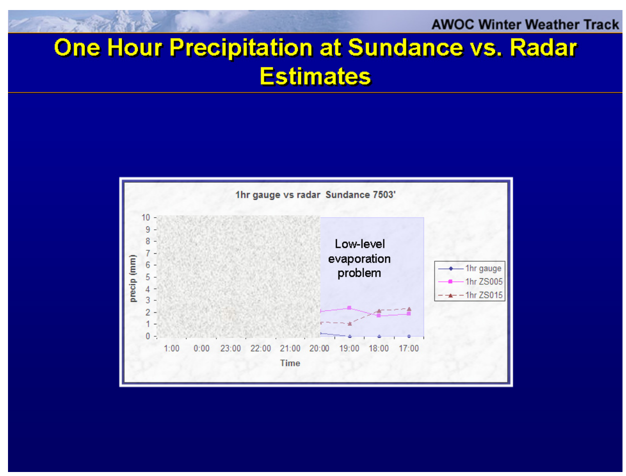
Student Notes:



41. One Hour Precipitation at Sundance vs. Radar Estimates

Instructor Notes: The gauge is now reporting slightly greater hourly totals than the radar estimate. It is likely now that feeder clouds have developed in the post-cold frontal air and that light seeder precipitation is being enhanced below the radar beam. What was a problem with low-level evaporation has perhaps become a problem of beam over-shooting.

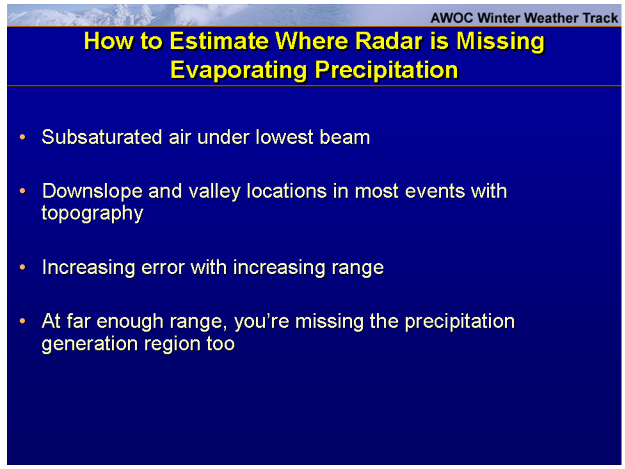
Student Notes:



42. How to Estimate Where Radar is Missing Evaporating Precipitation

Instructor Notes: Anytime there's subsaturated air, precipitation evaporates. And as long as this is occurring underneath the radar beam, you're going to run into potential precipitation overestimates. Most areas subjected to hours of virga without any compen-sating process to dry the air will saturate fairly quickly.

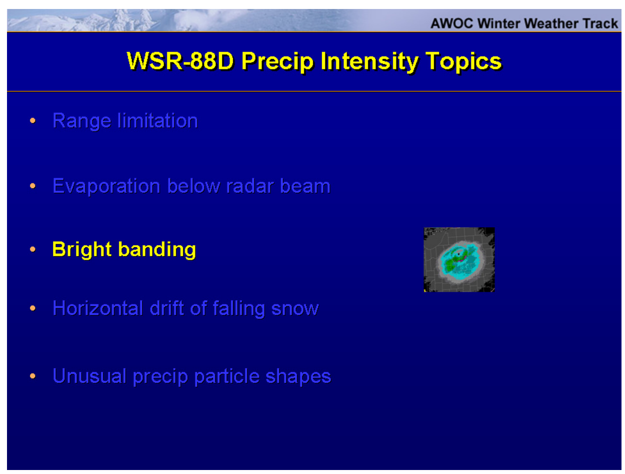
Student Notes:



43. WSR-88D Precip Intensity Topics

Instructor Notes: Five considerations adversely affect good precipitation estimates, especially snowfall. Limited range becomes exacerbated in the winter when cold temperature microphysics routinely occur closer to ground. Bright banding becomes more of an issue as the freezing level is low enough to interfere with the hybrid scan selection. Evaporation can also occur below the lowest radar beam.

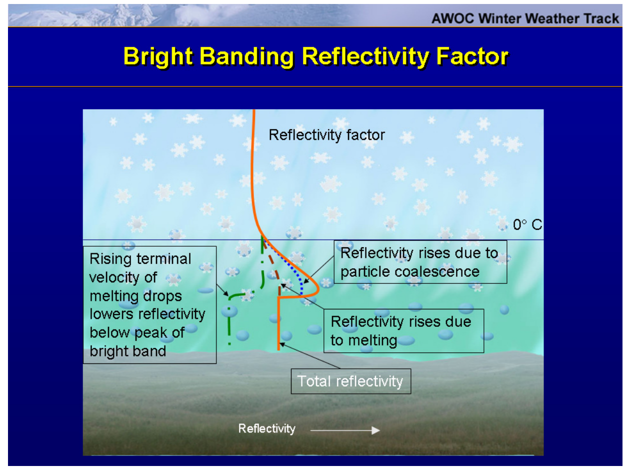
Student Notes:



44. Bright Banding Reflectivity Factor

Instructor Notes: Let's break down the mechanisms behind the bright band you see on radar because there is more than one. As snow flakes fall through the melting layer, water begins to coat their ice surfaces. The increased water coating helps colliding ice particles to stick together and snow flakes begin to increase in size. Larger particles form and the radar reflectivity increases. The liquid water coating itself also helps to increase radar reflectivity because the dielectric constant increases as ice changes phase to liquid. An offset to the increasing reflectivity occurs when the terminal velocity of the precipitation particles increases as melting accelerates. Increasing terminal velocity increases the separation between hydrometeors and lowers the reflectivity.

Student Notes:



45. Quiz Item 3

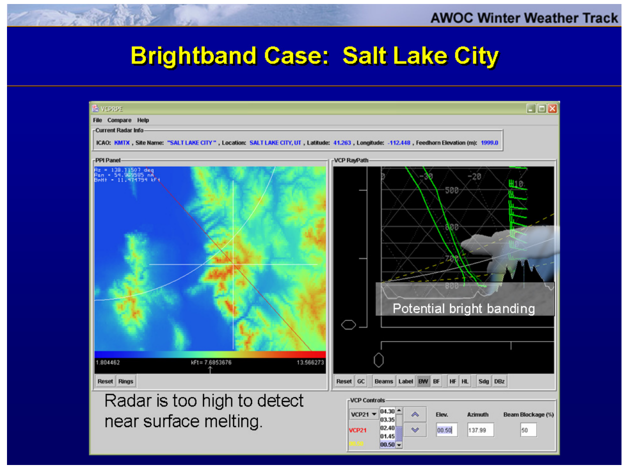
Instructor Notes: Take a moment to complete interactive quiz question #3.

Student Notes:

46. Brightband Case: Salt Lake City

Instructor Notes: In the Salt Lake area on this day, there may be sampling issues due to sub-beam evaporation and overshooting of upslope clouds. But there was no problem with bright banding even though there was a melting layer. The radar was simply too high. The radar location for once helps to eliminate one error source.

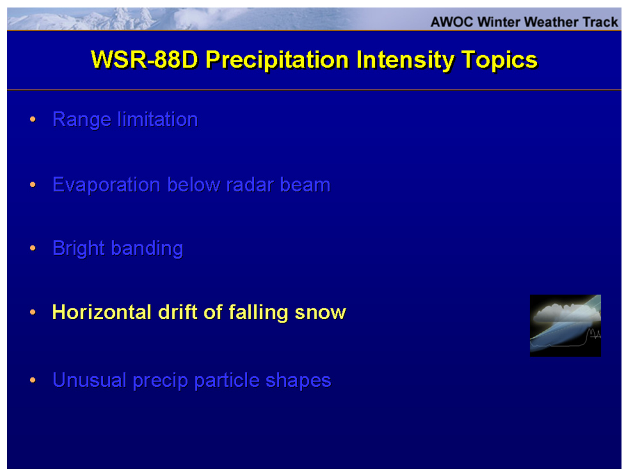
Student Notes:



47. WSR-88D Precipitation Intensity Topics

Instructor Notes: We will discuss precipitation errors coming from horizontal drift of falling snow.

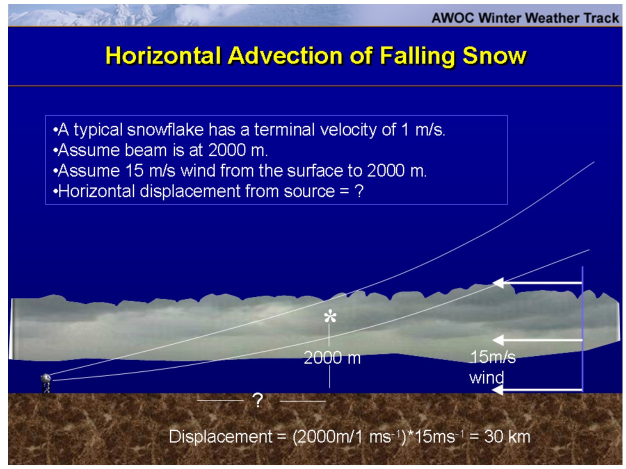
Student Notes:



48. Horizontal Advection of Falling Snow

Instructor Notes: Let's assume a snowflake has a fall velocity of 1 m/s at an altitude of 2 km. If we're experiencing a 15 m/s wind, how far would that snowflake be horizontally displaced before reaching the ground? You may pause this presentation if you would like to figure out the answer. I'll pause a few seconds here. If you've come up with 30 km, you are right. That could be literally in the next county.

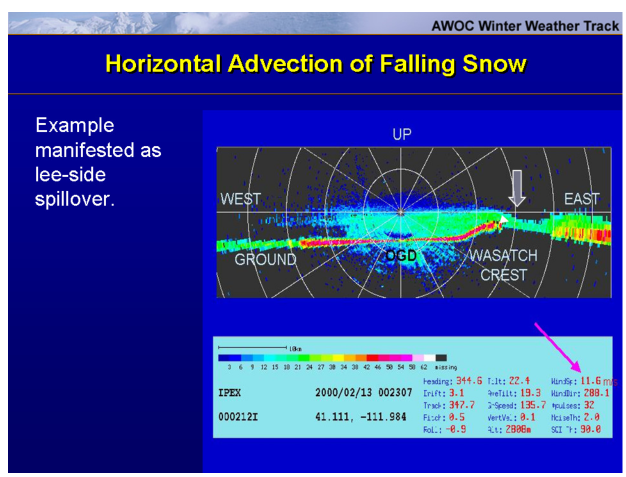
Student Notes:



49. Horizontal Advection of Falling Snow

Instructor Notes: An example of horizontal drift of falling snow is illustrated nicely here in this cross section taken from the P3 aircraft tail radar just west of the Wasatch mountains. Snow forming in the upslope drifts down the lee side of the crest for several miles. In this part of the country, the 'spillover' effect is a blessing for ski areas on the east side of the crest. In other parts of the country, this effect can occur if there is strong wind shear and rapidly moving transverse snowbands. If the location you're monitoring is far enough from the radar when one of these bands pass overhead, you may not have snow fall under the band for quite some time. Fortunately, this is one error source that can be mitigated by knowing the vertical wind profile and the height of the beam. The BLM attempted to implement a correction for horizontal drift of falling snow into the ZS algorithm. The results showed no significant improvement to the algorithm, possibly because other errors were so large. The error we'll talk about next is just one of those errors.

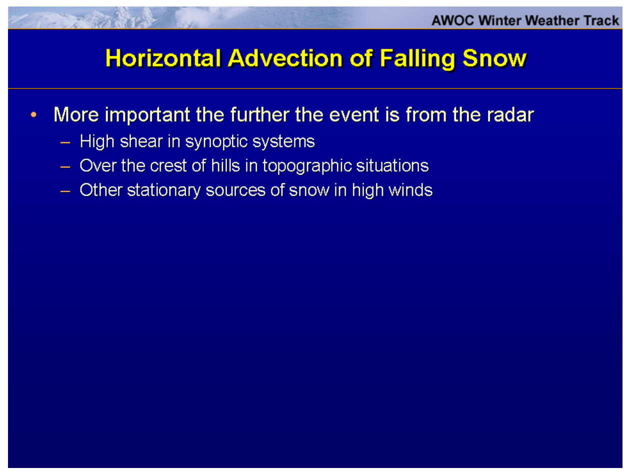
Student Notes:



50. Horizontal Advection of Falling Snow

Instructor Notes: What you want to look for are situations where either you have a situation where rapidly moving bands transverse to the mean flow exist in regions of high vertical wind shear or a stationary snow production source embedded in strong winds such as orographics. The high shear forces the snow to horizontally drift relative to the source of the snow. Lake effect is a stationary source of snow by relative standards but the snow often falls within the axis of the band, just downwind. There are times though at the end of a lake effect band where snow production is nonexistent and all the snow that is falling is simply drifting there from upwind.

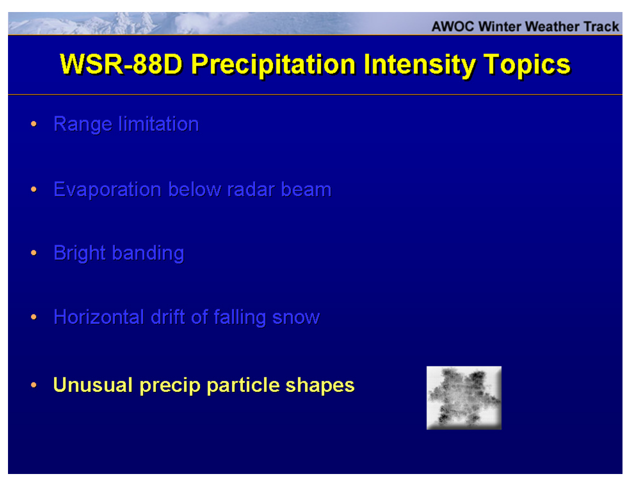
Student Notes:



51. WSR-88D Precipitation Intensity Topics

Instructor Notes: This final error source is probably the most intractable. Precipitation particle shape and size is something we'll talk about next.

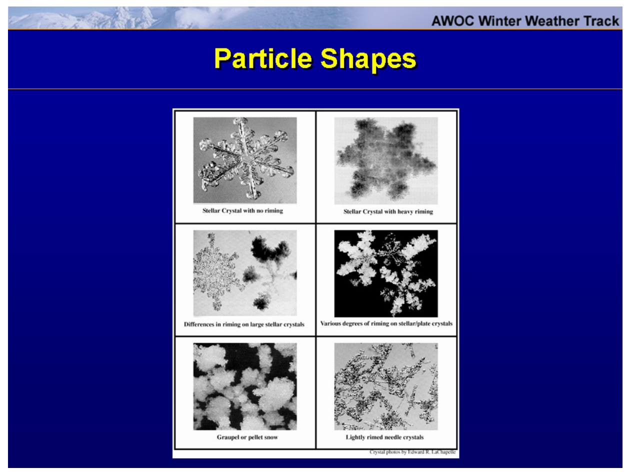
Student Notes:



52. Particle Shapes

Instructor Notes: Precipitation particle shape and size can significantly alter reflectivity without a corresponding increase in liquid equivalent precipitation rate. If you experience snow events, take a look at how the shapes and sizes of the snowflakes change over short periods of time. Many precipitation systems can contain a mixture of stratiform and convective elements with variations in vertical velocity profiles with respect to the thermal profile. The result is rapid changes in particle shapes. At this time, there is not much that can be done to adjust the ZS.

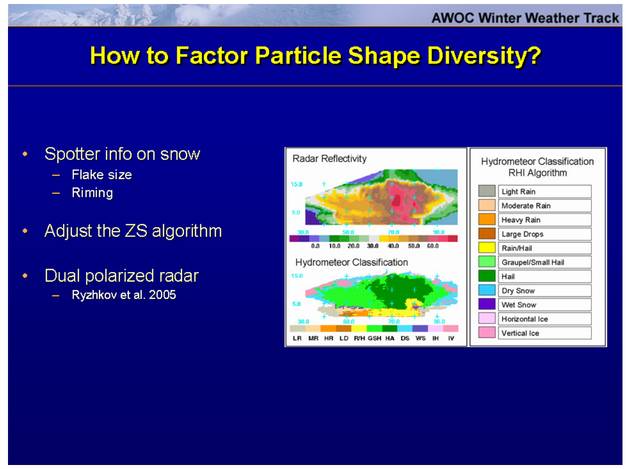
Student Notes:



53. How to Factor Particle Shape Diversity?

Instructor Notes: There are some tactics we could employ that would give us a handle on what direction the ZS algorithm error might be as a result of precipitation shape diversity. We could have spotters report to us flake size and type based on a template of images that we just saw in the last page. We could then adjust the ZS algorithm to help account for different precipitation particle shapes. However, once adjusted, it is adjusted for everyone in the radar domain and that's probably not a good solution. Really the best solution is one upon which the NWS is preparing to take, that is dual-polarized radar. Polarization diversity will allow us to detect different shapes and sizes of ice particles.

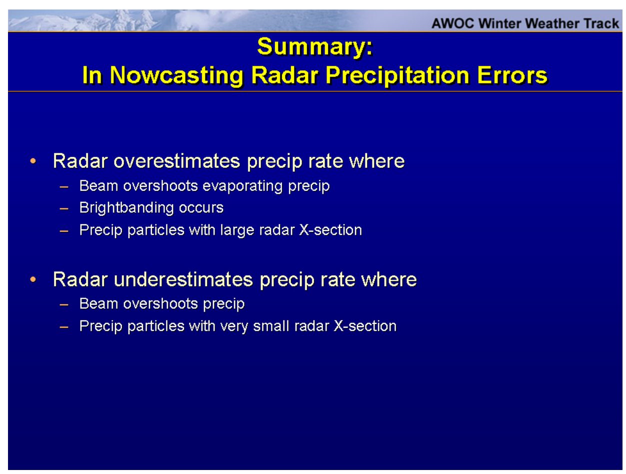
Student Notes:



54. Summary: In Nowcasting Radar Precipitation Errors

Instructor Notes: This slide summarizes the common reasons discussed in this lesson when radar algorithms overestimate or underestimate precipitation rate during snow events.

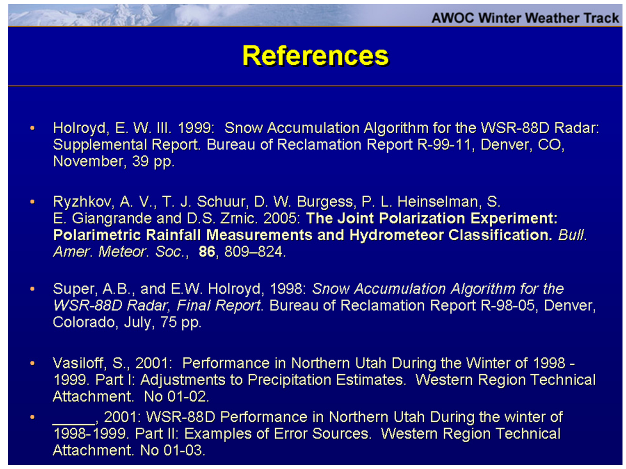
Student Notes:



55. References

Instructor Notes: This slide contains a list of all the references sited in this lesson.

Student Notes:



56. Have any Questions????

Instructor Notes: If you have any questions about this lesson, first ask your local AWOC facilitator. If you need additional help, send an E-mail to the address provided. When we answer, we will CC your local facilitator and may consider your question for our FAQ page. We strongly recommend that you take the exam as soon as possible after completing this lesson.

Student Notes: